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Technical Report No. 187

Seasonal prediction of Southern African rainfall using the UK Meteorological Office Unified Model

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Background

This paper is based on a presentation at the Seasonal Rainfall Forecasting Workshop on 25-26 September 1995 at Harare, Zimbabwe. The Workshop was arranged by the Harare Office of ODA, who kindly provided funding for participation. The paper will also appear in the Workshop Proceedings.

Introduction

There are two known sources of information from which it is possible to predict the future weather over a region. The first source is the state of the atmosphere at any particular moment, and knowledge of this state is gained from numerous observations around the world. When the current atmospheric state is fed into a computer forecast model it is normally possible to provide deterministic predictions of acceptable quality in the Northern Hemisphere extratropics out to about 5 days, although this limit may be higher or lower on a particular day. The theoretical limit of prediction using initial conditions in the extratropics is about 15 days. In lower latitudes, such as those occupied by most of southern Africa, the typical practical limit of prediction is about 1 or 2 days, a difference from the extratropics related to fundamental distinctions in atmospheric dynamics over the two regions.

The second source of predictive information is the distribution of global sea surface temperature (SST) anomalies, particularly those in tropical regions. These anomalies tend to persist for several months and can impose a consistent adjustment to the atmospheric circulation local to each anomaly. In turn these changes to the local atmosphere can influence regions remote from the SST anomaly in such a way that distinct impacts are noted on time scales of one or more seasons. For tropical and subtropical regions these impacts normally come in the form of increased or reduced rainfall. The most important region of SST anomalies in terms of impacts on regional climates lies in the tropical Pacific Ocean, where the anomalies are related to the phenomenon encompassing El Niño, La Niña and the Southern Oscillation, but anomalies in other ocean basins can also have importance. El Niño impacts can cover half the globe, including southern Africa. Because changes in SST anomalies are slow it is possible, either by assuming persistence of the anomaly or by

prediction of it, to use knowledge of remote impacts to provide rainfall predictions for some regions for one or more seasons. However, use of SST anomalies in no way helps to predict tropical *daily* weather beyond 1 or 2 days.

Most attempts at seasonal rainfall prediction in low latitudes has been based on links with SST anomalies, predominantly those in the tropical Pacific, although other circulation predictors have also been used (see review of Hastenrath, 1995). Essentially straightforward statistical models of links between rainfall and SST anomalies have been built for a number of regions of the world (e.g. Hackert and Hastenrath, 1986; Parthasarathy *et al.*, 1988; Ward and Folland, 1991; Folland *et al.*, 1991; Hastenrath *et al.*, 1993), including southern Africa (Landman, 1994; Jury, 1995; Hastenrath *et al.*, 1995), some of which are now being used for regular forecast production (see any edition of the Experimental Long-Lead Forecast Bulletin published by NOAA). All of these models effectively assume persistence of the SST anomalies. A more advanced methodology begins with prediction of the SST anomalies, either by statistical or numerical techniques, followed by application of a statistical model (as has been achieved for Zimbabwe by Cane *et al.*, 1994). At the top level a numerical atmospheric model can be used, either above SST anomalies provided by some other technique (normally persistence, or one of the models for SST prediction as has been tested by Hunt, 1995) or coupled with an ocean model so that prediction of the full atmosphere-ocean system is attempted. Work with coupled models is still at a preliminary stage although some predictions are now being produced (Ji *et al.*, 1994). Nevertheless the quality of the simple statistical predictions is often high and provides a challenge for the current state-of-the-art atmospheric models.

Southern African seasonal predictability

Most seasonal numerical modelling experiments assume that initial conditions are of no significance, the signal being extracted from the SST anomalies only (changes in ice cover and soil moisture can also affect the models). Results from a series of multi-year integrations over observed SST's using the UK Meteorological Office Unified Model (UM), designed to extract details of the model's response to changing global SST anomalies, are discouraging from the perspective of potential predictability of southern African rainfall variations; only

in the March to May season did the experiments suggest some potential predictability of rainfall, and then only at a relatively low level of skill compared to certain other tropical regions. However it has also been noted that the multi-year integrations also provided results indicating low rainfall predictability over the Sahel zone of Sub-Saharan North Africa, yet experiments in which the same model was used to provide seasonal predictions for the Sahel, in which the model was initialised with observed atmospheric conditions as well as being supplied with the latest SST anomalies (persisted through the prediction period), appeared to indicate prediction potential with the model. Currently the impacts of initial conditions on seasonal prediction, at least for the first season, are being examined in detail to establish whether their presence can account for the dichotomy in the two sets of results from the same model. In the interim research continues under the assumption that initial condition information is important to seasonal prediction, although details require elucidation.

Having suggested that numerical seasonal predictions over southern Africa may require knowledge of the initial atmospheric conditions, it should also be noted that prediction details are often sensitive to initial conditions, so that even a small change in the initial conditions can (sometimes but not always) lead to a substantial change in a prediction. Hence it is necessary to run an *ensemble* to provide seasonal predictions - an ensemble is a set of predictions each started from slightly different initial conditions. In the current work each ensemble has 10 members started from initial conditions separated by 24 hours.

Ensembles have been run for the two four-month austral summers of December to March 1986/87 and 1987/88, with the runs initialised in late November each year. Complete ensembles have been created using observed, persisted and climatological SST's, but only those using observed SST's are discussed here. It should be noted, though, that results with persisted SST's were similar to those with observed SST's, suggesting that predictability might be obtained simply using persistence of SST anomalies. A major El Niño occurred during 1986/87 and was associated with generally below-average rainfall over southern Africa. The El Niño had declined somewhat by 1987/88, a fact which may partially account for the somewhat increased southern African rainfall compared to 1986/87. Models may not always produce ideal representations of rainfall in all regions, a factor which makes interpretation of model predictions complex at times. However if a model is capable of

responding adequately to SST variations then differences in rainfall between two periods should be well described by the model. In the following, emphasis is placed on differences rather than on absolute predictions.

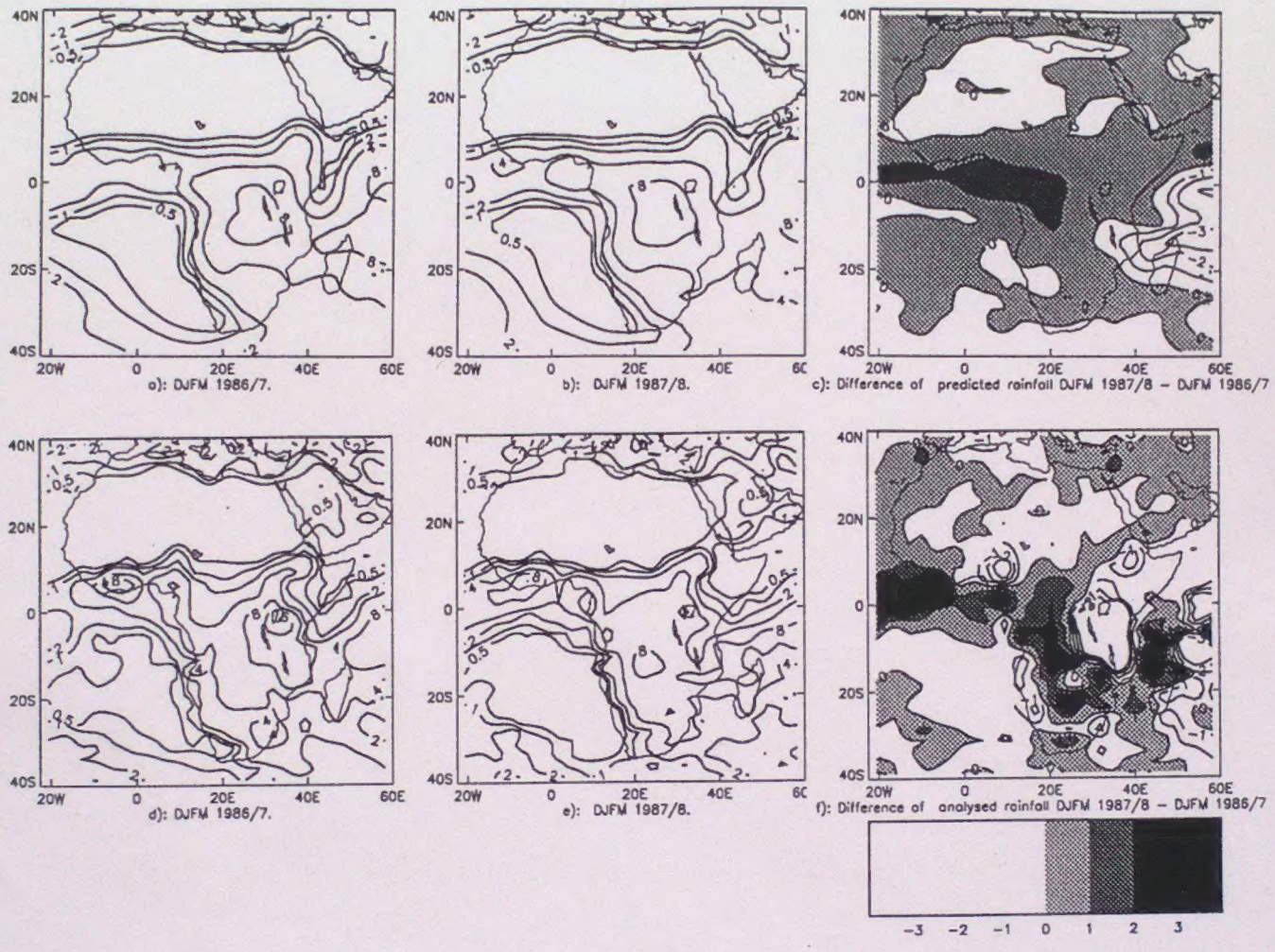

Fig 1. Ensemble mean rainfall predictions for a) December 1986 to March 1987 and b) December 1987 to March 1988; c) difference field between a) and b); model rainfall analyses for d) December 1986 to March 1987 and e) December 1987 to March 1988; f) difference field between d) and e). Contours in mm/day.

Ensemble mean predicted rainfall fields (i.e. averaged across all 10 ensemble members) for the two four-month seasons are shown in Figures 1a and 1b; these can be compared with rainfall analyses for the same seasons in Figures 1d and 1e (the use of model rainfall analyses is not ideal but is the best that can be achieved at present). Although the model predictions bear substantial overall similarities with the analyses there are areas, such as parts of southern Africa, where the predictions are clearly deficient. In part these deficiencies may be related to an inadequate model climatology. However, over most of southern Africa,

differences between predictions for the two years and for their corresponding observations were of the same sign (Figs. 1c and 1f), even if amplitudes of the simulated response were too low. Thus it might have proven possible to predict that 1987/88 would generally have been wetter than 1986/87. In fact over most of Africa differences were of the correct sign. The main area for which the wrong sign would have been predicted was over the western tropical Indian Ocean. Although predictions for this region have limited practical value it is of concern that the model achieved incorrect differences over a region for which observed SST anomalies were imposed.

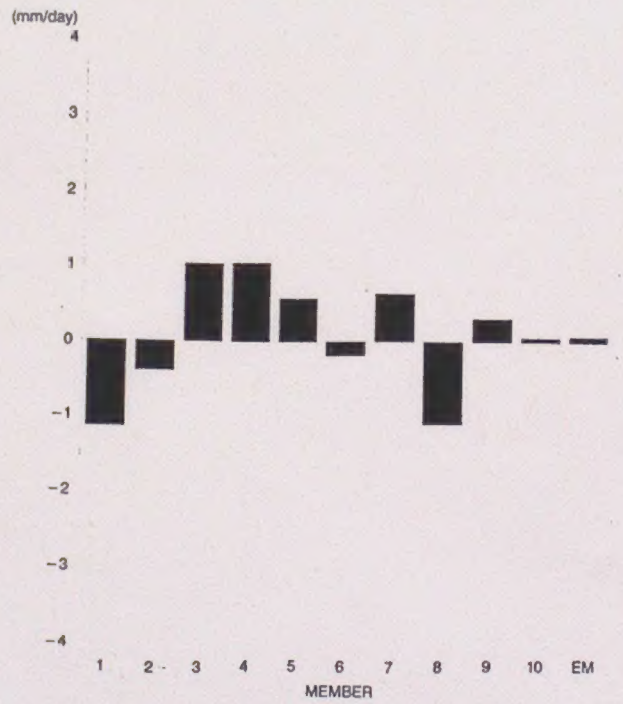

Fig 2. Rainfall anomalies (from a proxy model climate) for December 1986 to February 1987 for each ensemble member and the ensemble mean averaged over an area bound by 10°S, 20°S 30°S and 40°E.

Predicted total rainfall, averaged over an area bound by 10°S, 20°S, 30°E and 40°E and over the period December 1986 to February 1987, varies substantially between members

(Fig. 2 - the values are shown as anomalies from a proxy model climatology created over climatological SST's). Thus, even in a season with the strength of boundary forcing associated with a major El Niño, a single model prediction would not have given a reliable forecast for this region incorporating northern Mozambique. Maximum differences between members are of order 2 mm/day, or about 180 mm over the season, a substantial proportion of the normal seasonal fall. There are two realistic approaches to providing a prediction in this situation. Either the ensemble mean could be used as a deterministic prediction - in this case suggesting about normal rainfall, or perhaps slightly above normal - or the full ensemble could be used to provide a probabilistic prediction, the preferable approach. In simplest possible terms the probability forecast could be phrased as 60% probability of above-average (40% of below-average) rainfall, although a better approach would be to break down the distribution into, perhaps, terciles or quintiles, with probabilities predicted for each.

In conclusion the evidence presented above, together with further details omitted because of lack of space, suggest that this model may provide some predictability of southern African seasonal rainfall variations, although further experiments are required to validate this assertion. Further it can be suggested that sea surface temperature anomalies do appear to force changes in rainfall over southern Africa and that these anomalies are, in part, responsible for changes in the simulated rainfalls. However it appears that it is also necessary to provide correct initial conditions to the models in order to extract maximum predictability. Even having satisfied all the above conditions there is still a high level of sensitivity in the predictions to initial conditions such that it is necessary to run an ensemble. Given an ensemble, the optimum method of providing a prediction is in probabilistic terms.

An experimental southern African seasonal prediction for October to December 1995

As a preliminary test of the potential predictability for southern Africa revealed in this study two sets of ten-member ensembles have been created using persisted SST anomalies for July and August 1995 (tests indicate that persistence of anomalies appears to result in some loss of predictability compared to observed SST's, but that sufficient levels of predictability are retained), with initial conditions towards the end of each month. Both sets were run to the end of December 1995, so providing experimental predictions for the first part of the

1995/96 rainfall season. Results for both ensembles were similar, hence only those using August SST's will be discussed.

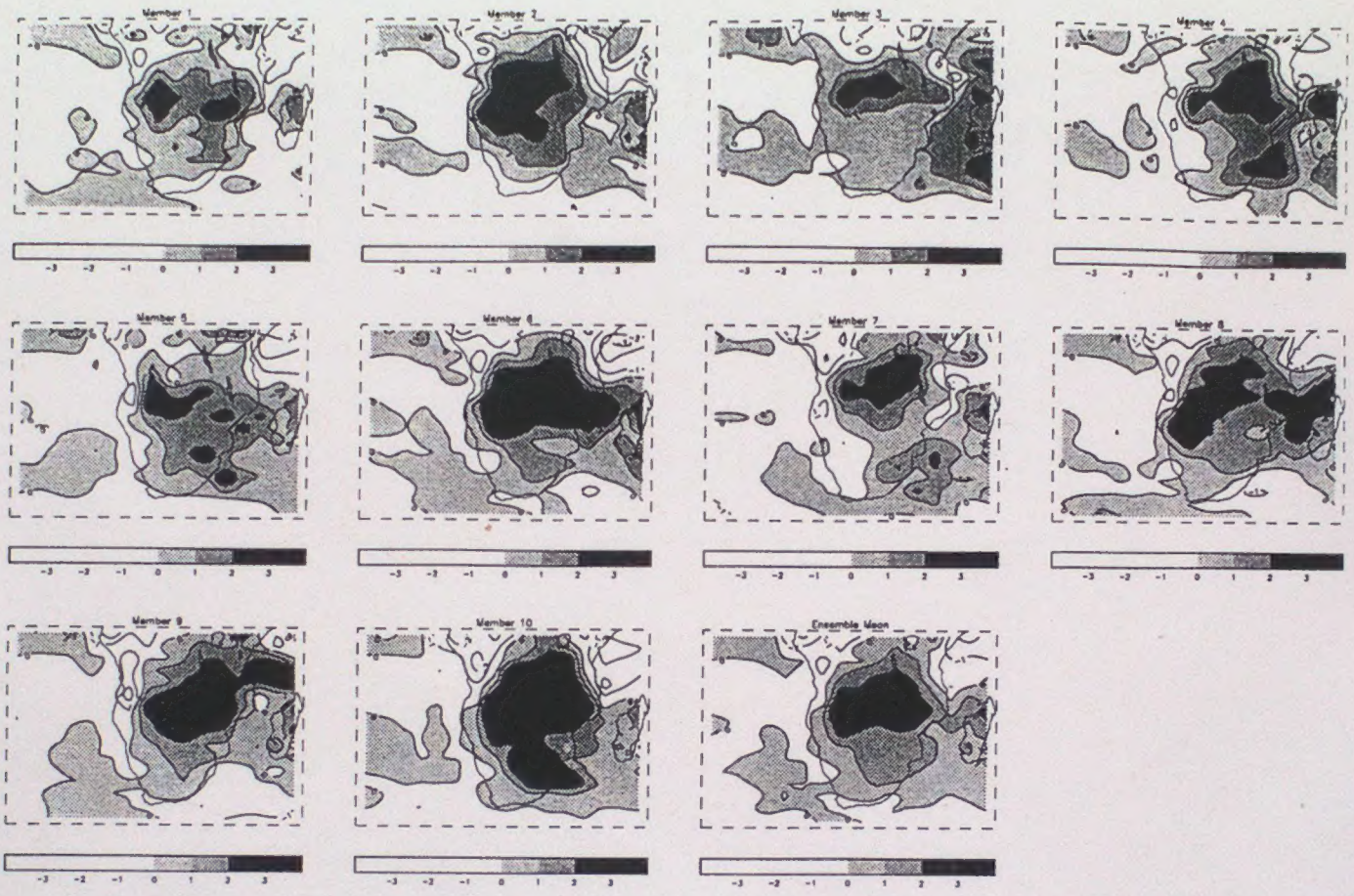

Fig 3. Predicted rainfall anomalies (from a proxy model climate) for October to December 1995 for each ensemble member plus the ensemble mean.

Above-average rainfall is predicted by all members across most of the subcontinent - the infrequent below-average predictions are generally restricted to the south-west and south of the region (Fig. 3). Hence as a deterministic prediction above-normal rainfall might be expected for most of the region. However it might be inopportune to forecast the magnitudes of the anomalies as inspection of Figure 3 indicates that anomalies differ substantially between members on the local scale. To illustrate this spatial variability average rainfall has been calculated for the October to December season for two regions, the first covering an area including northern Mozambique as used earlier (Fig. 4a), and the second a region mainly covering South Africa bounded by 25°S, 35°S, 15°E and 30°E (Fig. 4b). For both

areas all members predict above-average rainfall, but there is substantial variation between members (amounting to about 180 mm over the season for the northern area and 90 mm for the southern area). Thus in probabilistic terms there is a high likelihood of above-average rainfall, rainfall that may break the recent long-lived pattern of below-average rainfall over the region. In the southern region it appears more likely that rainfall will be only slightly above average, perhaps an anomaly of order 50 mm over the season, although there is a lesser possibility of anomalies reaching about 100 mm. In the northern region there is a more uniform distribution of predictions across a range of positive anomalies (from about 50 mm to about 220 mm for the season). Initial indications at the time of writing are that the predicted positive anomalies may be observed.

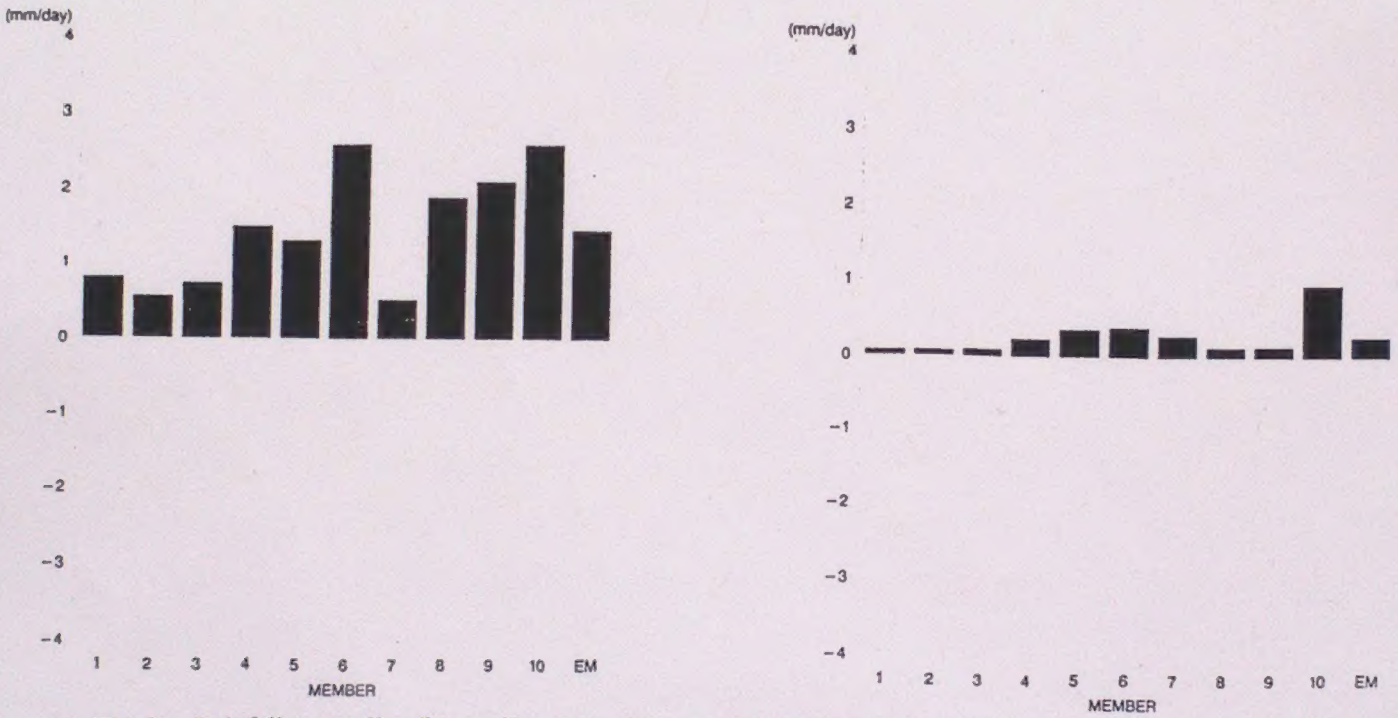

Fig 4. Rainfall anomalies (in mm/day from a proxy model climate) for October to December 1995 for each ensemble member and the ensemble mean averaged over areas bound by a) 10°S, 20°S, 30°E and 40°E and b) 25°S, 35°S, 15°E and 30°E.

Acknowledgements

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